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# COMPUTER TECHNIQUES TO SIMULATE CLIMATIC CONDITIONS IN MINES

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# COMPUTER TECHNIQUES TO SIMULATE CLIMATIC CONDITIONS IN MINES

by

M.K. Gangal* and A.E. Hall**

## ABSTRACT

The report discusses the computer simulation techniques available to determine the heat pick up of air in deep mines and to predict the cooling and ventilation requirements. The computer programs reported are for large scale planning, specific temperature prediction for individual sections of the mine, refrigeration planning and control, ventilation network planning and other programs for ventilation applications in mines with heat and humidity problems.

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# TECHNIQUES ASSISTÉES PAR ORDINATEUR POUR SIMULER LES CONDITIONS CLIMATIQUES DANS LES MINES

par

M.K. Gangal* et A.E. Hall**

## RÉSUMÉ

Le rapport présente les techniques de simulation assistées par ordinateur dont on dispose actuellement pour déterminer la quantité d'air absorbée par la chaleur et prévoir les besoins en ventilation et la demande de froid. Il s'agit de programmes machine utilisés pour la planification sur une grande échelle, la prévision d'une température particulière dans chaque section de la mine, la planification et le contrôle d'un système de réfrigération et d'un circuit d'aérage et d'autres programmes relatifs à l'application de techniques d'aérage dans les mines où la chaleur et l'humidité sont une source de problèmes.

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## INTRODUCTION

During the last 2 decades the application of computer techniques to simulate the underground mine environment has increased considerably. Many computer models have been developed around the world to simulate the mine environment due to problems such as dust, gas emissions, heat and humidity. These techniques have proven very valuable in predicting the various environmental parameters in the whole mine or a section of the mine.

The past traditional methods of approaching environmental problems were largely based on empirical or intuitive techniques. There are many parameters that affect the condition of ventilating air in mines. The complexity of the interrelated parameters needed for the mathematical modelling of mine environment can easily be handled by the use of a computer.

Modern mines are highly mechanized and are worked at greater depths. This creates problems of heat and humidity. High temperatures in mines have an adverse effect on the efficiency of workers. In Canada, heat problems are not yet extensive, but the increase of mechanization at greater depths has already resulted in the application of several types of cooling mechanisms.

The various computer techniques used to predict the environment of mines with heat problems are reviewed in this paper. No attempt is made here to deal with all of the hundreds of computer programs developed on this topic, but major programs, which can be adopted for use in Canadian mines, are discussed. The computer techniques discussed here are divided into the following five sections.

## LARGE SCALE PLANNING

The computer programs discussed in this section are for use in simulating whole mines or major parts of these. The programs have been developed for use in planning the quantities of ventilation and refrigeration required to maintain a satisfactory underground environment.

A mixed integer algorithm was developed by Magri and Unsted (1) to select discrete, feasible shaft diameters. This was part of an overall planning program to select optimum values for production rates, ventilation quantities, and refrigeration capacities, in order to maximize the net present value of a mining project. This model was further developed by Dos Santos

(2). This model utilized a ventilation network program to establish the required airflow rates in the different mining zones, and could be readily adapted to Canadian use. Wang et al. (3) developed a model for the optimal sizing of conventionally sunk circular shafts with concrete or shotcrete linings. The costs of sinking shafts of three different depths and six varying diameters were obtained from contractors. The model balanced the annual capital and operating costs to obtain the minimum overall cost for the life of a shaft installation. A noteworthy use of the program was an analysis of the effects of varying unit power costs on optimum shaft size. The model was primarily developed for use by Pennsylvanian coal mines, but representative figures could be obtained for Canadian deep level mines and can be used to carry out a similar analysis.

A computer model by Van der Walt and Whillier (4) developed equations on a mine-wide scale to calculate the heat pick-up from the rock in stopes, old areas, development drifts, haulages and travelling ways. The equations were used to calculate the water-rock thermal balance for the mine working areas and the thermal efficiency of production. These were new criteria developed to indicate the amount of cooling which could be achieved by chilling the mine service water. The water-rock thermal balance was defined as the amount of cold service water that would remove all the heat from the broken rock in advancing workings, together with the heat pick-up from the exposed rock surfaces within a specified distance of the face. It was expressed as tons of water per ton of rock broken.

The thermal efficiency of production was expressed as the dimensionless ratio of:

$$\frac{\text{Area where men are working}}{\text{Total excavated area which is ventilated}}$$

and could be used to evaluate the merits of different production plans.

Hemp (5) questioned the validity of certain parts of this program, particularly the calculation of heat flow rates from rock to air in tunnels such as development drifts, haulages and travelling ways. In reply, Van der Walt and Whillier (6) stated that the method had been modified and that the present version of the program (FRIDG5) has many new features incorporated into it; in particular a separate provision for handling the heat pick-up in

airways having established through ventilation. The heat pick-up in such airways is calculated using Gooch-Patterson mathematics. It was also stated that the methods used for predicting heat pick-up from the rock as given in the original paper are only applicable if the mine service water is cooled so that the temperatures in workings are more uniform. The model required the following input data:

a) Mine and shaft particulars comprising climatic conditions at the shaft and environmental design criteria such as required temperatures, ventilation volume specifications and expected underground water inflows and temperatures.
b) Mine production data giving rock breaking rates over the expected life of the property and whether the mining method is concentrated or scattered.
c) Additional data on the water temperature before cooling, age and size of workings and the distances from the face requiring to be cooled.

The program was specifically developed for South African use and would require modification for Canadian conditions.

A partial optimization program was developed by Hall (7) to determine the refrigeration to ventilation ratio for a mine or part of a mine on the basis of total cost. The program required the following input data:

a) Inlet and return air temperatures for the mining area.
b) The amount of heat generated in the mine.
c) Capital and operating costs of refrigeration circuits and ventilation fans.
d) The mine equivalent resistance value and the maximum and minimum airflows permissible.
e) Costs of driving additional airways.

The heat generated was estimated using the work of Barenbrug (8) and the program provided a quick, cheap, first estimate for planning purposes. The simplicity and low cost of the program made it very useful for examining the sensitivity of the solution to changes in the input parameters. This permitted the planner to determine the most important factors to be considered during the design process. A plotting routine was incorporated in

the program to provide a visual statement of the results for fast interpretation.

Hitchcock and Hoover (9) developed a computer program to compute the airflow throughout any network of underground tunnels resulting from natural and forced ventilation. The program also computed the temperature and humidity of the air resulting from heat-release by underground equipment, heat transfer from strata and evaporation from tunnel walls, as well as heat removed by ventilation and refrigeration equipment. The model consisted of three main components:

a) An aerodynamic subprogram to provide precise estimates of the airflows throughout the network.
b) A temperature and humidity subprogram to compute the environmental conditions throughout the network.
c) A deep heat-sink subprogram to compute the effects of long term heat addition from the surrounding earth.

A thermodynamic-based planning program was developed by Hall et al. (10) in which air temperatures throughout the network were determined from branch calculations which take into account shock and friction losses, fans, leakages into or out of the branch, and heat and evaporation from machinery. The program had the disadvantage that the meshes had to be selected by the user, although this was planned to be changed in a future modification.

Greuer (11) also developed a mine planning program. It has been based on thermodynamic ventilation network theory and requires the normal network input data plus the airway properties of length, perimeter, cross-sectional area and the rock parameters of temperature, thermal conductivity and thermal diffusivity for calculation of air temperatures. The program was designed for use in emergency planning during mine fires.

In order to apply these computer techniques, a great deal of information is being collected to quantify the amounts of heat liberated into individual mines. This is a simple measurement to obtain on a coarse scale and is likely to provide the basis for initial planning exercises. Surveys of this type are being conducted in the United States, Marks (12); West Germany, Mucke and Glodek (13), Hamm (14); South Africa, Hemp and Deglon (15) and the United Kingdom, Whittaker (16). Similar surveys could be readily performed for Canadian mines and then used for future planning purposes.

The use of the above computer programs, suitably modified for Canadian conditions, in conjunction with heat surveys would result in the development of accurate planning programs for the optimization of the environment and its cost in deep Canadian mines.

## TEMPERATURE PREDICTION FOR SECTIONS OF MINE

A great deal of work has been done in developing specific temperature prediction programs for mine circuits. The majority of this work has been done in South Africa and West Germany. The computer techniques for use at specific sections of the mine such as shafts, airways, development drifts and stopes are described in this section.

Starfield and Dickson (17) proposed a model which considered an airway in cross-section as a square void in an infinite extent of rock. The roof and sidewalls were assumed to be dry, while the footwall was assumed to be wet. Three degrees of wetness were considered:

a) Wet - corresponding to pools of water on the footwall surface.
b) Damp - corresponding to normal conditions.
c) Perfectly dry.

The temperatures of the rock surrounding the airway at successive time intervals were estimated by a finite difference solution of the heat conduction equation. Heat and moisture transfer from the rock to the air was assumed to depend on the rock surface temperatures and the air heat and moisture content and to be controlled by coefficients of heat and mass transfer. These coefficients were both functions of the air velocity and of the airway cross-sectional area. The wet and dry bulb gradients were calculated from the heat and moisture transferred, using the appropriate psychrometric equations. The program has been extensively used in South African gold mines and has been found to give good indications of the heat transferred from the rock. No allowance was made in the program for including heat from machinery or other sources and these have to be added to the results obtained. This is a disadvantage of the program and although it could be applied to Canadian mines, it is considered that, because of the amount of mechanized equipment underground, it would be preferable to write a new program allowing for the inclusion of additional heat sources.

Starfield (18) also produced a model of heat pick-up in stope faces. The program allowed for the amount of broken rock at the virgin strata temperature lying on the footwall and the length of time it released heat into the air before it was removed from the stope. The program was complex and assumed one-dimensional heat flux through the stope face and walls separately. Gould (19) later developed a complete two-dimensional stope model which he used to investigate the errors inherent to Starfield's one-dimensional model. Subsequently, Whillier (20) developed a simplified stope heat pick-up model which required pocket calculator computation.

McPherson (21) developed a program for the design of airflow and air cooling systems in gold mine stopes. The model determined the airflow distribution in the stope air passages - slusher gullies, faces and worked-out panels. There were no restrictions on the stope geometry or height. Air wet and dry bulb temperatures were calculated at the end of each branch and wet bulb temperatures at 5 m intervals along each gully and face. Radial heat flow into airways was assumed and Whillier's method was used to estimate the stope heat pick-up. Facilities were provided for the introduction of additional heat sources into any branch and air coolers were inserted on faces when the wet bulb temperature exceeded a limiting value. The program received limited use due to some testing problems and the large amount of input data required for limited results. It was predominantly designed as a teaching aid to illustrate the use of airflow controls and the necessity of achieving good air utilization at the stope faces. Whillier and Thorpe (22) developed a program for predicting the air temperature in a development heading. The program calculates results for 3 degrees of footwall wetness (wet, damp and dry) in the intake airway and for four different leakage rates. The program output shows the effect of changes in the wetness and leakage factors. The limitation of this program is that it relies on the existence of uniform rock conductivity over the length of the tunnel and makes no allowance for heat picked up from mechanical equipment or strata water in the intake airway. Gooch (23) produced a model of the face of a developing drift which could be used to calculate air temperatures and humidity increases in the face over the full period of a blasting cycle. The program requires the input of the tunnel size and information on the advance length and the amount of time that the broken rock remained in the tunnel. The model was developed to investigate the variation of the heat flow parameters into such tunnels and was based

on fundamental heat transfer theory. No allowance was made for calculating electrical or mechanical heat generation in the working area. The program has given fair agreement with practical measurements in South Africa and could be used by Canadian mines on an experimental basis.

Gooch (24) developed a model for the estimation of the air temperature increase in downcast shafts. The model considers the effects of the geothermal gradient, air quantity and shaft size and depth to calculate leaving air temperatures for 3 degrees of shaft wetness (wet, damp and dry). Tests of the program on gold mine shafts have revealed anomalies and its use has been limited. A recent study by Stroh (25) indicated that deep downcast shafts act as thermal flywheels and damp out surface temperature changes. An 11°C increase in surface dry bulb temperature resulted in a 3°C increase at the 1500 m level. An increase of 4°C in the surface wet bulb temperature caused only 1°C increase in the 1500 m wet bulb temperature. This damping effect requires greater investigation and the program should only be used in areas where the surface air temperature remains almost constant over a 24 hour period, or in shafts where the entering air is precooled to a constant temperature.

Considerable work has been done in West Germany to develop a suite of programs for mine temperature prediction. The work has been carried out by Mucke and Voss of the Mine Ventilation Research Station at Essen. Two programs have been developed for use in conjunction with long wall coal faces and have been used with fair success in West Germany and Britain, Voss (26). One program predicts conditions on the long wall face and the second program predicts air temperature in the intake and return airways. The programs calculate the effects of mechanized equipment and electrical heat losses and permit the simulation of refrigeration on the face and in the airways. Calculations are performed for the specific time of year requested by the user. The programs allow the geothermal properties of the rock to be input and used in the calculations. These programs were developed for use in European long wall coal mining, but could be tested on an experimental basis for use in Canada.

Gibson (27) has described a program for predicting the temperature distributions around mine ventilation network meshes. The program requires the following input data:

a) Airway physical data - length, cross-sectional area and depth.

b) Ventilation parameters - airflow quantity, pressure and entering temperatures.

c) Thermal parameters - age, rock conductivity and diffusivity, geothermal gradient, virgin strata temperature and wetness factors.

d) Position and power of all machinery.

The program was used in a British coal mine. On a 4000 m traverse the predicted wet and dry bulb air temperatures of 22.0/23.2°C compared well with the observed values of 20.8/22.0°C. The program description indicates that the model is intended to be one of a suite of interactive programs to be developed in the near future.

## REFRIGERATION PLANNING AND CONTROL

This section deals with the computer technique used in designing and controlling refrigeration machines and circulation systems in mines. Many refrigeration equipment manufacturers use in-house design programs for evaluating the optimum equipment for a client's needs. Prospective purchasers should be aware of these programs and ensure that they use these resources when selecting equipment. They must appreciate, however, that the results are only optimum to that manufacturer's designs and equipment. The reputable suppliers' techniques are of very high order and reliability, but it is not always possible to obtain the base criteria of heat transfer used in the programs because the market is highly competitive and such information is confidential.

Considerable work has been done in the chemical engineering industry in writing design programs for heat exchangers and heat transfer process. These programs normally have limited application to the mining field. It may be worthwhile, however, to check the availability of these programs before undertaking extensive design work.

Four programs of this type for shell-and-tube heat exchangers are described in the following United States Bureau of Mines information circular publications. The description included full program listings.

| Information Circular | Heat Exchanger Conditions |
|---|---|
| 8334 | No change in phase - pumping costs for both liquids are significant. |
| 8393 | No change in phase - only shell liquid pumping costs are significant. |
| 8399 | No change in phase - only tube side pumping costs are significant. |
| 8420 | Change in phase on shellside with zero pressure drop in the condensing fluid. |

Peters and Nicole (28) developed a cost-optimized design program for heat exchangers and condensers. The program has particular application to air-cooled finned-tube units using a heuristic technique. Heuristic programming was preferred because:

a) In detailed costing, the capital costs of two units of almost the same overall size can vary by factors of 2 or more depending on the selection of the bundle, section and fan sizes.

b) Capital costs of air cooled heat exchangers are usually considerably higher than those of shell-and-tube exchangers for comparable duties, thus providing more incentive for optimizing design.

c) Fan operating costs are significant, but considerable savings are possible by selective design with low peak power requirements and by providing means of fan control for off-design (winter) conditions.

A report by Blignaut (29) describes a program for the design and costing of counterflow water cooling towers. The report gives a full listing of the program which computes the lowest capital and operating cost of cooling water for a given combination of inlet and outlet water temperatures. The tower simulated is a film flow, counter-current, induced draft unit. The program is outdated and could be streamlined by replacing psychrometric table searching with the equations used in more recent programs. The costs of the component parts of the tower system would also require regular updating, but the program could easily be adapted to Canadian use.

Attempts have been made in South Africa to investigate the performance of complete refrigeration installations. This work differs from that of the equipment manufacturers who normally optimize the system components as individual units. Both attempts tried to predict the performance of underground spray, counterflow cooling towers which are normally designed by the mining company, independently of the refrigeration machine manufacturer.

The designer of such an installation has a large number of alternatives available. Decisions have to be made concerning pipe sizes, chilled water flow rates, heat exchanger sizes, positioning of the refrigeration machine, condenser water flow rates, cooling tower design, number or size of cooling coils, etc.

Hemp (30) wrote a computer program to calculate the effects of changes in the various parameters on cooling performance. The model assumed a fixed refrigeration plant condenser duty and that a given amount of air was available for heat rejection. The model calculated the condensing temperature for the fixed duty for given variables such as water flow rate, cooling tower height, tower air velocity, etc. The compressor motor power was calculated from the condensing temperature and a new heat transfer value determined. If this differed from the originally assumed value, the calculation was repeated until the two values agreed. Two versions of the program were prepared. The first one used Whillier's (31) cooling tower equation and the other used Hemp (32) Rand Mines equation. The programs were used to determine optimum values of water flow rate, air velocity and height for several assumed values of reject air quantities. The optimization was done in terms of total power consumed and no allowance was made for variations in capital costs.

Hemp recommended that further work should be done to design chilled water reticulation systems and to predict the performance of existing cooling plants when subjected to various conditions.

Hall and Unsted (33) developed a suite of experimental programs to determine the performance of the component parts of a refrigeration system: Cooling plant, cooling tower, reticulation lines, heat exchangers and cooling coils. The programs were prepared as a first stage in producing an overall simulation program for such installations.

Practical tests on the reticulation line, heat exchanger and cooling coil programs indicated that they gave good prediction of the performance of these components. The refrigeration machine program has been used at Vaal Reefs and is still capable of further development. A major problem is allowing for partial loading in the evaporator circuit. This is dependent on the compressor vane setting or on the operation of the hot gas bypass. The problem will be reduced on the new surface refrigeration machines as they are designed to work at full load for as long as possible during operation. The cooling tower program was based on empirical relationships developed from South African cooling tower performance figures. The relationship was found to have the same degree of accuracy as the relationship developed by Hemp (32). Problems occurred when upward sprays were used in such towers and further experimental work is required to improve these relationships.

Both program sets are capable of further development and could be extremely useful to any Canadian mining company installing major refrigeration capacity.

## AIR FLOW PLANNING

A large number of ventilation network programs have been developed for predicting airflow rates throughout mines. These programs are useful in deep hot mines as the results obtained can be used to calculate temperature increases and heat pick-up expected in the mining areas, and to calculate the costs and techniques required to improve unsatisfactory temperature conditions.

The programs suitable for use in mines with heat problems are those which allow for the compression of the air in the mine. McPherson's original program (34) based on incompressible flow equations has subsequently been developed in use by the British National Coal Board and South African and Australian mining companies. The program was further developed by Hall et al. (35,36) to allow for compressible airflow and natural ventilating energy effects in deep mines. The latest McPherson program has recently been used at Mount Isa Mines, Australia, Brown et al. (37). This version is based on a full thermodynamic balance and considers the circulating air to be compressible. Greuer's (11) thermodynamic ventilation program, discussed earlier, has been used in Canada by Stachulak (38) to determine the air flow rates at Creighton mine.

The CANMET-developed thermodynamic ventilation model is described by Hall et al. (39). This program permits the input of resistance using the Atkinson K-factor and the physical parameters of the airways. An optional cost estimate routine is included in the program to investigate the economic implications of modifying the network. A plotting program also provides a visual statement of the results of initial and final update of the network. In Canada this program has been used by Sherritt Gordon mines (40) to design the ventilation for their lower mine expansion. This program is suitable for use in Canada.

The earlier network programs were based on incompressible flow equations and are not suitable for deep mines. However these programs have been used in Canada to simulate the air flow of shallow mines. Some of these programs are listed later in this report.

In Canada the incompressible network program developed by Wang and Saperstein (41), which is an improvement of the earlier program by Wang and Hartman (42), has been widely used. This program has the capability of free-splitting, internal or external fans, natural ventilation pressure and fixed quantity branches. The application of this program in Canadian mines has been described by Gangal and Chakravorty (43) for a coal mine, Gangal (44), and Bell and Black (45) for an uranium mine, and Wedding and Nelson (46) for a salt mine.

## AUXILIARY PROGRAMS

Many auxiliary programs on psychromatic conditions of air are used by ventilation engineers. The South African Chamber of Mines developed mini-programs for calculating the performance and factor of merit of cooling towers and spray ponds.

Barometric survey programs developed for use in conjunction with network programs can also be used to determine heat and humidity pick-up. Harris (47) has written a program to calculate mine ventilation pressure losses using desk-top calculators.

A program for water flow analysis in refrigeration plant evaporator circuits was developed by the Chamber of Mines. Commercial bureaus also have water network programs which can be used for similar calculations.

Another program which may be of use in planning hot mines is the compressed air simulation program (Compair), Ryder and Stacey (48).

## AVAILABILITY OF COMPUTER PROGRAMS

Most computer programs can be obtained from the originating organizations. Some organizations require a payment for using their programs. Documentation is also usually available. Some of the programs are summarized below according to the following types of classification:

Type 1 - Large scale planning programs

Type 2 - Temperature prediction programs for sections of mine

Type 3 - Refrigeration planning and control programs

Type 4 - Air flow panning - ventilation network programs

Type 5 - Auxiliary programs.

| Originating Organisation | Program Name | Code Name | Type |
|---|---|---|---|
| Anmercosa Computer Services Ltd.<br>P.O. Box 1036<br>Welkom 9460<br>Republic of South Africa | A mathematical program for mine ventilation/refrigeration planning, 1978. | MS/A/11 | 1 |
| | Refrigeration plant monitoring program. | TMNP2300 | 3 |
| | Cooling coil program. | TENP1305 | 3 |
| | Water pipe-line program. | TENP1302 | 3 |
| | Water/water heat exchanger program. | TENP1301 | 3 |
| | Mine ventialtion network program. | TMNP1201 | 4 |
| | Mine ventilation network plot. | TMNP1500 | 4 |
| | Ventilation optimization aid program. | TMNP1800 | 4 |
| Chamber of Mines of South Africa<br>Research Laboratories<br>P.O. Box 809<br>Johannesburgh 2000<br>Republic of South Africa | Air and water cooling requirements for mines. | FRIDG5 | 1 |
| | Prediction of heat pick-up in mine airways. | Starfield | 2 |
| | Stope temperature simulation program. | TMPNET | 2 |
| | Prediction of heat pick-up in development ends. | Whillier | 2 |
| | Calculation of temperature and humidity increases in developing tunnels. | Gooch | 2 |
| | Calculation of temperature increases in downcast shafts. | Shaft | 2 |
| | Waterflow analysis in refrigeration evaporator circuits. | Waternet | 5 |
| | Compressed air simulation | CompairII | 5 |
| Y.J. Wang<br>Assistant Professor<br>West Virginia University<br>College of Mineral and<br>Energy Resources<br>Morgantown, W. Va.<br>26506 | Computer model for optimal sizing of conventionally sunk circular shafts. | --- | 1 |
| | Incompressible flow ventilation network program. | --- | 4 |
| Ventilation Research Station<br>Bergbau - Forschung GMBH<br>4300 Essen 13<br>Franz Fischer - Weg 61<br>West Germany | Prediction of air temperatures in developing drifts. | --- | 2 |
| | Prediction of air temperatures in longwall faces. | --- | 2 |
| | Prediction of air temperatures in longwall face airways. | --- | 2 |

| Originating Organisation | Program Name | Code Name | Type |
|---|---|---|---|
| U.S. Bureau of Mines<br>Superintendent of Documents<br>U.S. Government Printing Office<br>Washington, D.C.<br>20402 | Heat exchanger program listings - Information Circulars - 8334, 8393, 8399 and 8420 | --- | 3 |
| Chemical Engineering Group<br>Council for Scientific and<br>Industrial Research<br>Pretoria, Republic of S. Africa | Process design and costing of water cooling towers.<br>Cost optimized design of heat exchangers and condensers particularly air-cooled fin-tube units. | CHEM91 - TOWER<br>CHEM140 | 3<br>3 |
| R. Hemp<br>Group ventilation Engineer<br>Rand Mines Ltd.<br>P.O. Box 62370<br>Marshalltown 2107<br>Republic of South Africa | Refrigeration plant programs. | --- | 3 |
| M.J. McPherson<br>Professor<br>Dept. of Mining Engineering<br>University of California<br>Berkeley, California | Ventilation network program.<br>Temperature prediction program. (Gibson).<br>Barometric survey program. | ---<br>---<br>--- | 4<br>2<br>5 |
| R.V. Ramani<br>Pennsylvania State University<br>Mineral Sciences Building<br>Room #104<br>University Park<br>PA 16802 | Ventilation network program. | --- | 4 |
| Dept. of Mining and Minerals Engineering<br>Virginia Polytechnic and State University<br>Blacksburg, Virginia 24061 | Ventilation network program. | VENTSIM | 4 |
| M.K. Gangal<br>Mining Research Laboratories<br>CANMET<br>Energy, Mines and Resources<br>555 Booth Street<br>Ottawa, Ontario K1A 0G1 | Thermodynamic network program.<br>Barometric survey program.<br>Data verification program for above. | ---<br>---<br>--- | 4<br>5<br>5 |

| Originating Organisation | Program Name | Code Name | Type |
|---|---|---|---|
| C.J. Hall<br>University of Idaho<br>College of Mines<br>Moscow, Idaho 83843 | Thermodynamic network program. | --- | 1 |
| Parsons, Brinckerhoff,<br>Quade & Douglas Inc.<br>New York | Mines - network program (Hitchcock and Hoover). | MINES | 1 |
| Michigan Technological University<br>Mining Engineering Department<br>Houghton, MI<br>49931 | Thermodynamic network program | --- | 1 |
| Bethlehem Steel Corporation<br>Research Department<br>Bethlehem, Pennsylvania<br>18016 | Interactive ventilation planning system. | INVENT | 4 |
| A.E. Hall<br>Dept. of Mining and Mineral Process Engineering<br>University of British Columbia<br>Vancouver, B.C.<br>V6T 1W5 | Barometric survey program.<br>Psychrometric program. | ---<br>--- | 5<br>5 |
| Mining Industry Office<br>Control Data Corporation<br>P.O. Box O, Minneapolis<br>Minnesota 55440 | Network program with consideration to heating/cooling conditions. | MIVENDES | 4 |

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